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2. Patent application number *(The Patent Office will fill in this part)*	07 DEC 2000 **0029860.4**
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Sony United Kingdom Limited The Heights Brooklands Weybridge KT13 0XW United Kingdom
Patents ADP number *(if you know it)*	06522400003
If the applicant is a corporate body, give the country/state of its incorporation	UNITED KINGDOM
4. Title of the invention	Embedding Data in Material
5. Name of your agent *(if you have one)*	**D YOUNG & CO**
"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)	**21 NEW FETTER LANE LONDON EC4A 1DA**
Patents ADP number *(if you know it)*	**59006**

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D YOUNG & CO
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12. Name and daytime telephone number of person to contact in the United Kingdom — Richard Pratt — 023 80719500

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EMBEDDING DATA IN MATERIAL

The present invention relates to embedding data in material. Embodiments of the invention relate to watermarking material.

In this application material means one or more of video material, audio material and data material. In this context, video is generic to still images and moving images.

Steganography

Steganography is the embedding of data into material such as video material, audio material and data material in such a way that the data is imperceptible in the material.

Data may be embedded as a watermark in material such as video material, audio material and data material. A watermark may be imperceptible or perceptible in the material.

A watermark may be used for various purposes. It is known to use watermarks for the purpose of protecting the material against, or trace, infringement of the intellectual property rights of the owner(s) of the material. For example a watermark may identify the owner of the material.

Watermarks may be "robust" in that they are difficult to remove from the material. Robust watermarks are useful to trace the provenance of material which is processed in some way either in an attempt to remove the mark or to effect legitimate processing such as video editing or compression for storage and/or transmission. Watermarks may be "fragile" in that they are easily damaged by processing which is useful to detect attempts to remove the mark or process the material.

Visible watermarks are useful to allow e.g. a customer to view an image e,g. over the Internet to determine whether they wish to buy it but without allowing the customer access to the unmarked image they would buy. The watermark degrades the image and the mark is preferably not removable by the customer. Visible watermarks are also used to determine the provenance of the material into which they are embedded.

It is known to embed a watermark into material by applying a spatial frequency transform to the material embedding the watermark in the spatial frequency transform and applying an inverse transform to the watermarked material. A scaling factor is applied to the watermark. It is desirable to choose a scaling factor to improve the ability of the watermark to withstand unauthorised attempts to remove it; allow efficient authorised removal; reduce degradation of the unmarked material; and ensure that the mark is imperceptible where an imperceptible mark is desired. Those properties may be incompatible.

According to one aspect of the present invention, there is provided a method of embedding data in material, the method comprising the steps of:

producing transform coefficients Ci representing a spatial frequency transform of the material, and

combining the coefficients Ci with bits Ri of the data to produce modified coefficients Ci' where

$$Ci' = Ci + \alpha i\ Ri$$

the method further comprising determining αi for each unmodified coefficient Ci as a function $F\{Cn\}_i$ of a predetermined set $\{Cn\}_i$ of transform coefficients Cn which set excludes the coefficient Ci wherein the coefficients are serially ordered and the coefficients Cn are coefficients preceding coefficient Ci.

Preferably, the set {Cn}i of transform coefficients is:

a) a set consisting of unmodified coefficients; or

b) a set consisting of modified coefficients; or

c) a set comprising modified and unmodified coefficients.

Thus αi is adapted to each coefficient to which it is applied, allowing it to minimise degradation of the material. That also allows αi to make the embedded data more robust against processing which intentionally or unintentionally damages the embedded data.

The set $\{Cn\}_i$ of coefficients used to calculate αi associated with coefficient Ci excludes Ci. As will become apparent from the method of removing the data Ri, that allows exact recalculation of αi in the removal process and thus exact removal of Ri to

restore the original material if no processing has occurred, and no clipping of the image in the spatial domain has occurred.

The invention allows αi to be related to the other coefficients from which it is calculated by any suitable function.

The transform may produce coefficients Ci in a plurality of frequency bands. The transform coefficients forming the set $\{Cn\}_i$ may be all in the same band. The transform coefficients forming the set $\{Cn\}_i$ may be in a plurality of bands. Using a set of coefficients $\{Cn\}_i$ in a plurality of bands allows the data Ri to be concealed in the material using material properties in bands other than the band containing the data Ri.

In a preferred embodiment, the coefficients are serially ordered and the coefficients Cn are unmodified coefficients preceding coefficient Ci. During removal of the embedded data such ordering allows the coefficients to be used to calculate αji for a subsequent coefficient Cj.

In such circumstances, the set $\{Cn\}i$ may be:

a) the set consisting of unmodified coefficients; or

b) a set consisting of modified coefficients; or

c) a set comprising modified and unmodified coefficients.

According to another aspect of the present invention there is provided a method of removing data embedded in material according to the method of said one aspect, the method comprising the steps of:

determining the values of bits Ri of the data;

calculating, for each modified coefficient Ci', the value of the said function $F\{Cn\}_i$ of the corresponding set $\{Cn\}_i$ of coefficients Cn to determine αi; and

for each modified coefficient Ci', subtracting therefrom $\alpha i.Ri$ to restore the unmodified coefficient value Ci, wherein the coefficients are serially ordered and the coefficients Cn are coefficients preceding coefficient Ci.

In a preferred embodiment, αi is calculated from a set $\{Cn\}i$ of unmodified coefficients. The method thus uses the restored coefficient Ci as an unmodified coefficient Cn of another set $\{Cn\}_j$ of unmodified coefficients for restoring another coefficient Cj'. It will be appreciated that the set $\{Cn\}_i$ excludes the coefficient Ci'. The set $\{Cn\}_i$ is of unmodified coefficients allowing αi to be calculated exactly from

the material in which the data Ri is embedded. As a modified coefficient Ci' is restored to its original value it is then available to be used to calculate αj for another coefficient Cj'.

In a preferred embodiment, the coefficients are serially ordered and the coefficients Cn are unmodified coefficients preceding coefficient Ci. During removal of the embedded data such ordering allows the coefficients to be used to calculate αi for a subsequent coefficient j

In such circumstances, the set {Cn}i may be:

a) the set consisting of unmodified coefficients; or

b) a set consisting of modified coefficients; or

c) a set comprising modified and unmodified coefficients.

These and other aspects of the invention are specified in the claims to which attention is invited.

For a better understanding of the present invention, reference will now be made by way of example to the accompanying drawings in which:

Figure 1 is a schematic block diagram of a watermark embedding and removal system;

Figure 2 is a more detailed schematic block diagram of an embedder of the system of Figure 1;

Figures 3A and B illustrate an example of a window of coefficients and how the window relates to a coefficient Ci being modified to embed a bit of a watermark;

Figure 4 is a flow diagram of a method of calculating strength α in accordance with an example of the invention;

Figure 5 is a schematic block diagram of a watermark decoder;

Figure 6 is a schematic block diagram of a watermark remover;

Figure 7 is a flow diagram of a method of calculating strength α in accordance with an example of the invention;

Figure 8 is a schematic diagram of an alternative, illustrative, set of coefficients usable to calculate α;

Figure 9 is a schematic diagram illustrating the operation of frame stores in the embedder of Figure 2 and the remover of Figure 6;

Figures 10 and 11 are diagrams used herein below to describe wavelets transforms; and

Figures 12 and 13 are diagrams of data structures of UMIDs.

Overview

Figure 1 illustrates a watermarking system, generally 10, for embedding, recovering and removing a watermark onto or from a video image I. The watermarking system 10 comprises a source 110 of the image I, a strength adapter 180. a watermark embedder 120, a watermark decoder 140, a watermark remover 130 and a store 150. The decoder and remover may be coupled to the embedder via a channel 125 which may include a video processor, and/or a store.

In overview, the watermark embedder 120 embeds a watermark onto a video image 115 to form a watermarked image I', the watermark decoder 140 recovers the watermark from the watermarked image I' and the watermark remover 130 removes the watermark from the watermarked image I' to produce a restored image I". The restored image I" may not equal the original image I, especially if the channel 125 includes a processor and/or if clipping of the image in the spatial domain occurs.

The watermark embedder 120 receives, in this example, as watermark data, a UMID. UMIDs are described in the section *UMIDs* below. The strength adapter 180 determines the magnitude α of the watermark in relation to the video image I, the strength-being determined such that the watermark may be recovered whilst minimising its perceptibility to a viewer of the watermarked image I'. The watermarked image I' may then be stored, and/or transmitted and/or routed for further processing, in the channel 125.

The watermark decoder 140 generates a restored UMID 145 from the watermarked image I'. The watermark remover 130 generates a restored image I" from the watermarked image I' using the restored UMID.

Watermark embedder. Figure 2.

Figure 2 illustrates the watermark embedder 120 in more detail. The watermark embedder 120 comprises pseudo-random sequence generator 220, an error correction coding generator 200, a wavelet transformer 210, an inverse wavelet transformer 250, a first combiner 230, a data converter 225 and a second combiner 240. The wavelet transformer 210 includes a frame store FS1. The inverse

transformer 250 includes a frame store FS2. The frame store FS1 stores a frame of unmodified coefficients Ci. The frame store FS2 stores a frame of modified coefficients Ci'.

The error correction coding generator 200 receives the UMID and outputs an error correction coded UMID to the first combiner 230. The pseudo-random sequence generator 220 outputs a pseudo-random binary sequence (PRBS) Pi, where i is the i^{th} bit of the sequence, to the first combiner 230. The PRBS has a length L x J of bits where J is the number of bits in the error correction encoded UMID. Each bit j of the error correction encoded UMID then modulates a section of length L of the PRBS. The first combiner 230 logically combines the error correction encoded UMID with the PRBS to produce a watermark having bits Ri. A bit Wj=0 of the error correction encoded UMID inverts L bits of the PRBS. A bit Wj=1 of the error correction encoded UMID does not invert the PRBS. Thus bits Wj of the error correction encoded UMID are spread over L bits of the PRBS. The data converter 225 converts binary 1 to symbol +1 and binary 0 to symbol −1 to ensure that binary 0 bits contribute to a correlation value used in the decoder of Figure 5.

The wavelet transformer 210 receives the video image I from the source 110 and outputs wavelet coefficients to the second combiner 240. Wavelets are briefly discussed in the section *Wavelets* below.

The second combiner 240 receives the watermark Ri, the wavelet coefficients Ci and watermark strength αi and outputs modified coefficients Ci' where

$$Ci' = Ci + \alpha i\, Ri$$

The inverse wavelet transformer 250 receives the modified coefficients Ci' and outputs a spatial domain watermarked image I'.

The embedder includes an ECC generator 200. The use of error correction coding to produce an error correction coded UMID is advantageous since it allows the UMID 175 to be reconstructed more readily should some information be lost. This provides a degree of robustness to future processing or attacks against the watermark. The use of a pseudo-random sequence Pi to generate a spread spectrum signal for use as a watermark is advantageous since it allows the error correction coded UMID 205 to be spread across a large number of bits. Also, it allows the watermark to be more effectively hidden and reduces the visibility of the watermark. Applying the

watermark to a wavelet transform of the image is advantageous since this reduces the perceptibility of the watermark. Furthermore, the strength of the watermark is adjusted by αi to ensure that the watermark is not perceptible.

The operation of the error correction code generator 200 will now be described. The error correction code generator 200 receives a UMID. Typically the UMID will be a binary sequence of 31 bytes. The error correction code generator 200 typically outputs a 511 bit error correction coded binary sequence. Various error correction coding schemes are known. One approach uses BCH coding which corrects up to 31 bit errors. The error correction rates can be further improved by using knowledge of the UMID format to help correct errors. One such approach is to check for invalid dates times GPS locations etc.

The watermark is preferably embedded in predetermined regions of the wavelet transformed image. Most preferably the upper horizontal (hH,lV)and upper vertical (lH,hV) bands are used. These bands are chosen as watermarks embedded in these regions are not readily perceptible. The length of the pseudo-random sequence may be chosen such that the watermark fills the predetermined regions in each wavelet image. The regions in which the watermark is embedded may be within a border of unmodified coefficients thereby allowing the image to the spatially shifted without the watermark being lost.

<u>Calculating α. Figures 3 and 4.</u>

In accordance with an illustrative embodiment of the invention, for each coefficient Ci, a value of α, αi is calculated. αi is calculated as

$$\alpha i = F\ \{Cn\}_i,$$

where $\{Cn\}_i$ is a set of unmodified wavelet coefficients excluding Ci, which set may vary with i, that is respective values of αi are functions F of respective sets $\{Cn\}_i$. This is shown as step S8 in Figure 4.

The coefficients $\{Cn\}_i$ of the set may be in the same wavelet band as Ci or may be in different bands from Ci and from each other as described below with reference to Figure 8.

If the coefficients are in the same band as Ci, they are preferably in a window adjacent Ci. For example the set comprises N coefficients Ci-1 to Ci-N as shown in Figure 3 and the embodiment will be described in the following with reference to that.

The number N of coefficients may vary with Ci; thus for generality N is denoted as Ni.

The function F may be any suitable function. In this illustrative embodiment F is such that

$$\alpha i = \mathrm{F}\{\mathrm{Cn}\}i = \frac{1}{Ni}.\sqrt{\sum C_n^2} \text{ for } n = i\text{-}1 \text{ to } i\text{-}N \text{ for } Ni \neq 0 \text{ and } \alpha i = \mathrm{k} \text{ for Ni} = 0.$$

Figure 3A is a map of wavelet coefficients in a frame store 300, the coefficients being in level 1 of a wavelet transform. In a preferred embodiment, the coefficients Ci are modified only in the upper horizontal hH, lV and upper vertical lH, hV bands to embed the watermark. However, coefficients in other bands and/or in other levels may be modified to embed a watermark. In the following only band hH, lV is considered.

The wavelet coefficients are stored in the frame store 300 (also denoted FS1 in Figure 2) and in this example are stored as shown in Figure 3A grouped in the bands. The coefficients are serially ordered. For example they may be serially ordered by a raster scan thereof. Other scanning patterns are known. Assuming serial ordering of the coefficients in each band, for each coefficient Ci to be modified, there is defined a set $\{Cn\}_i$ (herein also referred to as a 'window') of Ni coefficients excluding Ci. The set $\{Cn\}_i$ consists of the Ni coefficients Ci-1 to Ci-Ni preceding coefficient Ci on the same line , up to a maximum of for example M most recent coefficients. It will be noted that in the band hH, lV coefficient C1 has no preceding coefficients, C2 has only one preceding coefficient, and so on. For coefficient C1 αi is set to a predetermined value K. For subsequent coefficients the set comprises the totality of preceding coefficients.

Thus αi is defined individually for each coefficient Ci to be modified. In the example above it is defined by the set of Ni unmodified coefficients preceding Ci. By choice of the appropriate function F, αi is adapted to the image such that image degradation can be minimised. In addition as will be discussed below in the section *Remover*, this allows αi to be recalculated from the watermarked image coefficients,

after those have been restored to their original values. This improves the accuracy of restoring the original image.

Referring to Figure 4 the illustrative procedure for calculating Ci' is as follows:-

The calculation procedure starts at step S2. At step S4, i is initialised with value 0. At step S6, i is incremented by 1 to calculate $\alpha 1$ at step S8 for coefficient C1'. At step S10 the value of modified coefficient C1' is calculated. The procedure then reverts to step S6 and i is incremented. The procedure continues until all coefficients have been modified.

In addition, the calculation of αi may be modified in one or both of the following ways:-

1) If $\alpha i<\alpha_{TL}$, it is incremented to α_{TL}, where α_{TL} is a lower threshold; and if $\alpha i> \alpha_{TH}$ it is reduced to α_{TH}, where α_{TH} is an upper threshold.

2) The magnitude $|C_n|$ of each coefficient is compared with a threshold C_{TH}. If $|C_n|>C_{TH}$ then Cn is not included in the calculation of αi,; or if $|C_n|>C_{TH}$, then C_n is clipped to $(C_n/|C_n|)C_{TH}$

Watermark decoder and remover. Figures 5 and 6.

Decoder Figure 5

The operation of the watermark decoder 140 will now be explained in more detail with reference to Figure 5. The watermark decoder 140 receives the watermarked image I' and outputs the restored UMID. The watermark decoder 140 comprises a wavelet transformer 310, a reference pseudo-random sequence (PRBS) generator 320, a correlator 330, a selector 340 and a error correction coding decoder 350. The PRBS generated by the generator 320 is identical to that generated by the PRBS generator 220 of Figure 2 and converted by a data converter (not shown) to values +1 and –1 as described above.

The wavelet transformer 310 receives the watermarked image I' and, in known manner, outputs the modified wavelet coefficients Ci'. The correlator 330 receives the reference pseudo-random sequence PRBS having symbols Pi of values +1 and -1 from the pseudo-random sequence generator 320, and the wavelet coefficients Ci' and

outputs a watermark image bit correlation sequence 335. The watermarked image bit correlation sequence is determined in the following way.

The modified wavelet coefficients $Ci' = Ci + \alpha_i R_i$ where R_i are bits of PRBS modulated by error-correction encoded bits Wj of UMID. In the example given above there are 511 bits Wj. Each bit Wj modulates L bits of PRBS. There are JL bits in the modulated PRBS.

For each error correction encoded bit Wj, the correlater 330 calculates a correlation value

$$S_j^{'} = \sum_{i=jL+1}^{jL+L} Ci'.Pi$$

where j = 0, 1, 2... T-1, and T is the number of error correction encoded bits. In this example T=511. A sequence 335 of correlation values $S_j^{'}$ is produced.

The correlation sequence 335 is received by the selector 340 which outputs an uncorrected UMID 345. The selector 340 outputs a bit value "1" for a value of S' greater than 0 and a bit value "0" for S' less than or equal to 0. The error correction code decoder 350 receives the uncorrected UMID 345 and in known manner outputs the restored UMID 145.

The reference PRBS Pi is synchronised with the modulated PRBS in the watermarked image. For that purpose a synchroniser (not shown) is used. Such synchronisation is known in the art.

Remover Figure 6.

The watermark remover 130 receives the restored UMID 145, and the watermarked image I' and outputs a restored image I''. The watermark remover 130 comprises a pseudo-random sequence generator 420 for generating a reference pseudo-random sequence Pi identical to that produced by generators 220 and 320, a spread spectrum signal generator 430 which produces, via a data converter 425, a restored watermark Ri' having bit values +1 and -1 from the restored UMID 145 and the pseudo-random sequence Pi. The reference sequence Pi is synchronised with the modulated sequence in the watermarked image in known manner.

The watermark remover 130 further comprises a wavelet transformer 410 which produces modified wavelet coefficients Ci' from the watermarked image I', a

strength estimator 460 for calculating αi and a combiner 440 which calculates restored wavelet coefficient values according to the equation

$$Ci = Ci' - \alpha_i . Ri'.$$

The restored wavelet coefficients C are fed to an inverse wavelet transformer 450 which outputs the restored image I".

Calculating αi. Figure 7.

In accordance with the illustrative embodiment of the invention, αi is calculated in the embedder as described above in the section *Calculating α* The estimator 460 of the remover of Figure 6 recalculates α in analogous manner from coefficients Ci which have been restored to their original values.

Thus referring for example to Figure 3A and to Figures 6 and 7, the modified coefficients Ci' are stored in a frame store 300 indicatd as FS3 in the wavelet transformer of Figure 6 in the same way as shown in figure 3A and they are serially ordered in the same way as described with reference to Figure 3A. It will be recalled that coefficient Ci' has no preceding coefficients so $\alpha 1 = k$ and $C1 = C1' - kR1$. For each subsequent coefficient Ci, αi is calculable from the set of Ni of preceding restored coefficients, all of which have been restored to their original value according to

$Ci = Ci' - \alpha_i . Ri'$.

Referring to Figure 7, the calculation procedure starts at step S5. At step S7, i is initialised to 0. At step S9, i is incremented by 1 to calculate $\alpha 1$ at step S11 for coefficient C1'. At step S13 the original value C1 is calculated from coefficients C1'. The procedure then reverts to step S9 and i is incremented. The procedure continues until all coefficients Ci' have been restored to their original values Ci.

As in the embedder of Figure 2, the calculation of α may be modified in one or both of the following ways:-

1) If $\alpha i < \alpha_{TL}$, it is incremented to α_{TL}, where α_{TL} is a lower threshold; and if $\alpha i > \alpha_{TH}$ it is reduced to α_{TH}, where α_{TH} is an upper threshold.

2) The magnitude $|Cn|$ of each coefficient is compared with a threshold C_{TH}. If $|Cn| > C_{TH}$ then Cn is not included in the calculation of αi; or

if $|Cn| > C_{TH}$, then C_n is clipped to $(Cn/|Cn|)C_{TH}$.

Modifications.

As mentioned above the coefficients from which the value of αi is calculated may be in different bands to the related coefficient Ci which is to be modified or restored to its original value. Thus by way of example, referring to Figure 8, the set of coefficients $\{Cn\}_i$ used to calculate αi of band hH, lV may be in the other bands. In the example of Figure 8 the set $\{Cn\}_i$ is shown as including coefficients C1i, C2i and C3i which are at positions related to the position of coefficient Ci. In this way, image properties in other bands are taken into account in calculating αi to ensure that the watermark is imperceptible.

The coefficients C1i, C2i and C3i used to modify or restore Ci, may be coefficient which are never modified. That can be done by modifying only coefficients in one or more bands such as hH, lV and leaving the coefficients in other bands unmodified. Alternatively at least some of the coefficients C1i, C2i and C3i used to modify or restore Ci may be modified. That can be done by storing the coefficients in a frame store 300 as shown in Figure 3 or 8 and by reading out coefficients in an order which allows the procedures of Figures 4 and 7 to be followed.

It will be appreciated that whilst the foregoing discussion refers for ease of explanation to only 3 coefficients C1i, C2i and C3i in 3 bands in one level, in practice many more coefficients may be used and the coefficients may be in more than three bands and in more than one level.

Other transforms

Whilst the invention has been described by way of example with reference to Wavelet transforms, it may be used with other transforms for example DCT.

Other material

Whilst the invention has been described by way of example with reference to material comprising video material (still or moving images), it may be applied to other material, for example audio material and data material.

PRBS

As described hereinabove, the PRBS has a length of L J where J is the number of bits in a UMID. Thus each bit Wj of the UMID modulates a section of length L of the PRBS. Instead, it may have a length of L bits and be repeated for each bit j of the UMID.

Other Watermark data.

Whilst the invention has been described by way of example with reference to UMIDs as the watermark data, it may be used with other data as the watermark.

Using modified coefficients to calculate αi

The foregoing embodiment calculates αi using unmodified coefficients. In alternative embodiments α is calculated using modified coefficients or a combination of modified and unmodified coefficients. The coefficients Ci are serially ordered. The coefficients used to calculate αi for coefficient Ci are coefficients preceding i on the serial order.

Referring to Figures 2, 6 and 9 frames stores FS1, FS2, FS3 and FS4 are provided in the wavelet transformer 210, the inverse wavelet transformer 250, the wavelet transformer 410 and the inverse wavelet transformer 450. Frame stores FS1and FS4 store unmodified coefficients. Frame stores FS2 and FS3 store modified coefficients C'i.

Thus there are available both at the encoder and at the remover serially ordered sets of unmodified and modified coefficients.

In the embedder of Figure 2, as coefficients Ci in store FS1 are modified, they are stored in FS2 as coefficients Ci'. Thus modified coefficients Ci' are available to calculate αi. Thus the set $\{Cn\}i$ used to calculate αi for modifying coefficient Ci may comprise modified coefficients C' preceding Ci optionally together with unmodified coefficients C preceding Ci.

At the remover modified coefficients Ci' are stored in store FS3. As the coefficients are restored, restored coefficients Ci are stored in store FS4. Thus modified coefficients C' are available to calculate αi optionally together with restored coefficients C

As diagrammatically shown in Figure 9, sets of coefficients preceding a coefficient C*i* or C*i*' are present in all four frame stores FS1, FS2, FS3 and FS4.

Shape of sets {Cn}*i*

A set {Cn}*i* may have any convenient shape. Where αi is calculated only from coefficients preceding C*i*, the set may consist of coefficients immediately preceding C*i*. Where the coefficients are raster scanned to serially order them, the set may consist of coefficients on the same scanning line as C*i*. Alternatively, it may consist of coefficients on that line and a preceding line. Other shapes are possible.

Wavelets

Wavelets are well known and are described in for example " A Really Friendly Guide to Wavelets " by C Valens, 1999 and available at http://perso.wanadoo.fr/polyvalens/clemens/wavelets/wavelets.html.

Valens shows that the discrete wavelet transform can be implemented as an iterated filter bank as used in sub-band coding, with scaling of the image by a factor of 2 at each iteration.

Thus referring to Figure 11, a spatial domain image is applied to a set of high pass HP and low pass LP filters. At level 1, the first stage of filtering, the image is filtered horizontally and vertically and, in each direction, scaled down by a factor of 2. In level 2, the low pass image from level 1 is filtered and scaled in the same way as in level 1. The filtering and scaling may be repeated in subsequent levels 3 onwards.

The result is shown schematically in Figure 10. Figure 10 is a representation normal in the art. At level one the image is spatially filtered into four bands: the lower horizontal and vertical band, lH_1, lV_1; the upper horizontal band hH_1, lV_1; the upper vertical band lH_1, hV_1; and the upper horizontal and vertical band, hH_1, hV_1. At level 2, the lower horizontal and vertical band, lH_1, lV_1 is filtered and scaled into the lower horizontal and vertical band, lH_2, lV_2; the upper horizontal band hH_2, lV_2; the upper vertical band lH_2, hV_2; and the upper horizontal and vertical band, hH_2, hV_2. At level 3 (not shown in Figure 10), the lower horizontal and vertical band, lH_2, lV_2 is further filtered and scaled.

UMIDs

The UMID or Unique Material Identifier is described in SMPTE Journal March 2000. Referring to Figure 11 an extended UMID is shown. It comprises a first set of 32 bytes of basic UMID and a second set of 32 bytes of signature metadata.

The first set of 32 bytes is the basic UMID. The components are:

•A 12-byte Universal Label to identify this as a SMPTE UMID. It defines the type of material which the UMID identifies and also defines the methods by which the globally unique Material and locally unique Instance numbers are created.

•A 1-byte length value to define the length of the remaining part of the UMID.

•A 3-byte Instance number which is used to distinguish between different 'instances' of material with the same Material number.

•A 16-byte Material number which is used to identify each clip. Each Material number is the same for related instances of the same material.

The second set of 32 bytes of the signature metadata as a set of packed metadata items used to create an extended UMID. The extended UMID comprises the basic UMID followed immediately by signature metadata which comprises:

•An 8-byte time/date code identifying the time and date of the Content Unit creation.

•A 12-byte value which defines the spatial co-ordinates at the time of Content Unit creation.

•3 groups of 4-byte codes which register the country, organisation and user codes

Each component of the basic and extended UMIDs will now be defined in turn.

The 12-byte Universal Label

The first 12 bytes of the UMID provide identification of the UMID by the registered string value defined in table 1.

Byte No.	**Description**	**Value (hex)**
1	Object Identifier	06h
2	Label size	0Ch

3	Designation: ISO	2Bh
4	Designation: SMPTE	34h
5	Registry: Dictionaries	01h
6	Registry: Metadata Dictionaries	01h
7	Standard: Dictionary Number	01h
8	Version number	01h
9	Class: Identification and location	01h
10	Sub-class: Globally Unique Identifiers	01h
11	Type: UMID (Picture, Audio, Data, Group)	01, 02, 03, 04h
12	Type: Number creation method	XXh

Table 1: Specification of the UMID Universal Label

The hex values in table 1 may be changed: the values given are examples. Also the bytes 1-12 may have designations other than those shown by way of example in the table. Referring to the Table 1, in the example shown byte 4 indicates that bytes 5-12 relate to a data format agreed by SMPTE. Byte 5 indicates that bytes 6 to 10 relate to "dictionary" data. Byte 6 indicates that such data is "metadata" defined by bytes 7 to 10. Byte 7 indicates the part of the dictionary containing metadata defined by bytes 9 and 10. Byte 10 indicates the version of the dictionary. Byte 9 indicates the class of data and Byte 10 indicates a particular item in the class.

In the present embodiment bytes 1 to 10 have fixed preassigned values. Byte 11 is variable. Thus referring to Figure 12, and to Table 1 above, it will be noted that the bytes 1 to 10 of the label of the UMID are fixed. Therefore as shown in Figure 13 they may be replaced by a 1 byte 'Type' code T representing the bytes 1 to 10. The type code T is followed by a length code L. That is followed by 2 bytes, one of which is byte 11 of Table 1 and the other of which is byte 12 of Table 1, an instance number (3 bytes) and a material number (16 bytes). Optionally the material number may be followed by the signature metadata of the extended UMID and/or other metadata.

The UMID type (byte 11) has 4 separate values to identify each of 4 different data types as follows:

'01h' = UMID for Picture material

'02h' = UMID for Audio material

'03h' = UMID for Data material

'04h' = UMID for Group material (i.e. a combination of related essence).

The last (12th) byte of the 12 byte label identifies the methods by which the material and instance numbers are created. This byte is divided into top and bottom nibbles where the top nibble defines the method of Material number creation and the bottom nibble defines the method of Instance number creation.

Length

The Length is a 1-byte number with the value '13h' for basic UMIDs and '33h' for extended UMIDs.

Instance Number

The Instance number is a unique 3-byte number which is created by one of several means defined by the standard. It provides the link between a particular 'instance' of a clip and externally associated metadata. Without this instance number, all material could be linked to any instance of the material and its associated metadata.

The creation of a new clip requires the creation of a new Material number together with a zero Instance number. Therefore, a non-zero Instance number indicates that the associated clip is not the source material. An Instance number is primarily used to identify associated metadata related to any particular instance of a clip.

Material Number

The 16-byte Material number is a non-zero number created by one of several means identified in the standard. The number is dependent on a 6-byte registered port ID number, time and a random number generator.

Signature Metadata

Any component from the signature metadata may be null-filled where no meaningful value can be entered. Any null-filled component is wholly null-filled to clearly indicate a downstream decoder that the component is not valid.

The Time-Date Format

The date-time format is 8 bytes where the first 4 bytes are a UTC (Universal Time Code) based time component. The time is defined either by an AES3 32-bit audio sample clock or SMPTE 12M depending on the essence type.

The second 4 bytes define the date based on the Modified Julian Data (MJD) as defined in SMPTE 309M. This counts up to 999,999 days after midnight on the 17th November 1858 and allows dates to the year 4597.

The Spatial Co-ordinate Format

The spatial co-ordinate value consists of three components defined as follows:

•Altitude: 8 decimal numbers specifying up to 99,999,999 metres.

•Longitude: 8 decimal numbers specifying East/West 180.00000 degrees (5 decimal places active).

•Latitude: 8 decimal numbers specifying North/South 90.00000 degrees (5 decimal places active).

The Altitude value is expressed as a value in metres from the centre of the earth thus allowing altitudes below the sea level.

It should be noted that although spatial co-ordinates are static for most clips, this is not true for all cases. Material captured from a moving source such as a camera mounted on a vehicle may show changing spatial co-ordinate values.

Country Code

The Country code is an abbreviated 4-byte alpha-numeric string according to the set defined in ISO 3166. Countries which are not registered can obtain a registered alpha-numeric string from the SMPTE Registration Authority.

Organisation Code

The Organisation code is an abbreviated 4-byte alpha-numeric string registered with SMPTE. Organisation codes have meaning only in relation to their registered Country code so that Organisation codes can have the same value in different countries.

User Code

The User code is a 4-byte alpha-numeric string assigned locally by each organisation and is not globally registered. User codes are defined in relation to their registered Organisation and Country codes so that User codes may have the same value in different organisations and countries.

CLAIMS

1. A method of embedding data in material, the method comprising the steps of:

producing transform coefficients Ci representing a transform of the material, and

combining the coefficients Ci with data symbols Ri to produce modified coefficients Ci' where

$Ci' = Ci + \alpha i\ Ri$

the method further comprising determining αi for each unmodified coefficient Ci as a function $F\{Cn\}_i$ of a predetermined set $\{Cn\}_i$ of transform coefficients Cn which set excludes the coefficient Ci wherein the coefficients are serially ordered and the coefficients Cn are coefficients preceding coefficient Ci.

2. A method according to claim 1 wherein the coefficients of the set $\{Cn\}_i$ vary with i.

3. A method according to claim 1 or 2, wherein the number Ni of coefficients in the set $\{Cn\}i$ varies with i.

4. A method according to claim 1, 2 or 3, wherein the coefficients of the set $\{Cn\}_i$ have a predetermined positional relationship with the coefficient Ci to be modified.

5. A method according to claim 1, 2, 3 or 4, wherein the coefficients represent a spatial frequency transform of the material.

6. A method according to claim 1, 2, 3 or 4, wherein the coefficients represent a wavelet transform of the material.

7. A method according to claim 6, wherein the transform produces coefficients Ci in a plurality of bands.

8. A method according to claim 7, wherein the transform coefficients forming the set $\{Cn\}_i$ are all in the same band.

9. A method according to claim 7, wherein the transform coefficients forming the set $\{Cn\}_i$ are in a plurality of bands.

10. A method according to any preceding claim wherein the said function $F\{Cn\}_i$ is such that

$$\alpha i = \frac{1}{Ni}.\sqrt{\sum C_n^2} \text{ for } n = i\text{-}1 \text{ to } i\text{-}N_i \text{ for } N_i \neq 0 \text{ and } \alpha i = k \text{ for } N_i = 0$$

where Ni is the number of coefficients Cn in set i.

11. A method according to any preceding claim, wherein the said data symbols Ri are of a pseudo random symbol sequence having symbols Pi modulated by data Wj to be embedded.

12. Apparatus for embedding data in material, comprising

a transformer for producing transform coefficients Ci representing a transform of the material, and

a combiner for combining the coefficients Ci with data symbols Ri to produce modified coefficients Ci' where

$Ci' = Ci + \alpha i\ Ri$

the apparatus further comprising

a calculator for calculating αi for each unmodified coefficient Ci as a function $F\{Cn\}_i$ of a predetermined set $\{Cn\}_i$ of transform coefficients Cn which set excludes the coefficient Ci, wherein the coefficients are serially ordered and the coefficients Cn are coefficients preceding coefficient Ci.

13. Apparatus according to claim 12, wherein the coefficients of the set $\{Cn\}_i$ vary with i.

14. Apparatus according to claim 12, or 13, wherein the unmodified coefficients of the set $\{Cn\}_i$ have a predetermined positional relationship with the coefficient Ci to be modified.

15. Apparatus according to claim 12, 13 or 14, wherein the coefficients represent a spatial frequency transform of the material.

16. Apparatus according to claim 12, 13, or 14, wherein the coefficients represent a wavelet transform of the material

17. Apparatus according to claim 16, wherein the transformer produces coefficients Ci in a plurality of frequency bands.

18. Apparatus according to claim 17, wherein the transform coefficients forming the set $\{Cn\}_i$ are all in the same band.

19. Apparatus according to claim 18, wherein the transform coefficients forming the set $\{Cn\}_i$ are in a plurality of bands.

20. Apparatus according to any one of claims 12 to 19, wherein the said function $F\{Cn\}_i$ is such that

$$\alpha i = \frac{1}{N_i}\cdot\sqrt{\sum C_n^2} \text{ for } n = i\text{-}1 \text{ to } i\text{-}N_i \text{ for } N_i \neq 0 \text{ and } \alpha i = k \text{ for } N_i = 0$$

where Ni is the number of coefficients Cn in set i.

21. A method or apparatus according to any preceding claim, wherein the data is imperceptibly embedded in the other material.

22. A method or apparatus according to any preceding claim, wherein the set {Cn}i consists of unmodified coefficients.

23. A method or apparatus according to any one of claims 1 to 21, wherein the set $\{Cn\}_i$ consists of modified coefficients preceding Ci where the coefficients are serially ordered.

24. A method or apparatus according to any one of claims 1 to 21, wherein the set $\{Cn\}_i$ comprises at least one modified coefficient and at least one unmodified coefficient.

25. A method of removing data embedded in material according to the method of any one of claims 1 to 12, the detecting method comprising:

determining the values of the data symbols Ri;

calculating, for each modified coefficient Ci', the value of the said function $F\{Cn\}_i$ of the corresponding set $\{Cn\}_i$ of coefficients Cn to determine αi; and

for each modified coefficient Ci', subtracting therefrom αi.Ri to restore the unmodified coefficient value Ci, wherein the coefficients are serially ordered and the said set {Cn}i consists of modified coefficients preceding coefficient Ci.

26. A method according to claim 25, wherein the said set {Cn}i consists of restored coefficients Ci and comprising the further step of using a restored coefficient Ci as a coefficient of another set {Cn}j of coefficients for restoring another coefficient Cj.

27. Apparatus according to claim 25 or 26, wherein the said set {Cn}i comprises at least one modified coefficient and at least one restored coefficient, the coefficients preceding C'i.

28. A method according to any one of claims 25 to 27, wherein the step of determining the values of the data bits Wj embedded in material according to the method of claim 11, comprises correlating a reference pseudo random symbol sequence with the modified coefficients Ci' and decoding the correlation values to determine the data Wj modulating the pseudo random sequence and remodulating the reference sequence with the said data to restore Ri.

29. Apparatus for removing data embedded in material according to the method of any one of claims 1 to 11, the apparatus comprising:

a processor for determining the values of the symbols Ri;

a calculator for calculating, for each modified coefficient Ci', the value of the said function $F\{Cn\}_i$ of the corresponding set $\{Cn\}_i$ of coefficients Cn to determine αi; and

a subtractor which, for each modified coefficient Ci', subtracts therefrom $\alpha i.Ri$ to restore the unmodified coefficient value Ci, which thereby becomes available for use as an unmodified coefficient of another set $\{Cn\}_i$ of unmodified coefficients Cn for restoring another coefficient Ci', wherein the coefficients are serially ordered and the said set {Cn}i consists of coefficients preceding coefficient Ci.

30. Apparatus according to claim 29, wherein the said set {Cn}i consists of restored coefficients Ci and comprising the further step of using a restored coefficient Ci as a coefficient of another set {Cn}i+1 of coefficients for restoring another coefficient Ci+1.

31. Apparatus according to claim 30, wherein the said set {Cn}i consists of modified coefficients preceding coefficient Ci.

32. Apparatus according to claim 30, wherein the said set {Cn}i comprises at least one modified coefficient and at least one restored coefficient, the coefficients preceding C'i.

33. Apparatus according to claim 29, 30, 31 or 32, wherein the means for determining the values of the data bits Wj embedded in the material according to the method of claim 12, comprises a correlator for correlating a reference pseudo random symbol sequence with the modified coefficients Ci', a decoder for decoding the correlations to determine the data Wj modulating the modulated sequence and a modulator for remodulating the reference sequence with the said data to restore Ri.

34. A computer program product arranged to carry out the method of any one of claims 1 to 11 when run on a computer.

35. A computer program product arranged to carry out the method of any one of claims 25 to 30 when run on a computer.

36. A method or apparatus according to any preceding claim, wherein the material is video material.

37. A method or apparatus according to any one of claims 1 to 35, wherein the material is audio material.

38. A method or apparatus according to any one of claims 1 to 35, wherein the material is audio/visual material.

39. A method of embedding data in material substantially as herein before described with reference to the accompanying drawings.

40. Apparatus for embedding data in material substantially as herein before described with reference to the accompanying drawings.

41. A method of removing data embedded in material substantially as herein before described with reference to the accompanying drawings.

42. Apparatus for removing data embedded in material substantially as herein before described with reference to the accompanying drawings.

ABSTRACT

EMBEDDING DATA IN MATERIAL

A method of embedding data in material, comprises the steps of:

producing transform coefficients Ci representing a spatial frequency transform of the material, and

combining the coefficients Ci with the data bits Ri to produce a modified coefficient Ci' where

$$Ci' = Ci + \alpha i\ Ri$$

the method further comprising determining αi for each unmodified coefficient Ci as a function $F\{Cn\}_i$ of a predetermined set $\{Cn\}_i$ of transform coefficients Cn which set excludes the coefficient Ci.

Preferably, the set {Cn}i of transform coefficients is:

a) a set consisting of unmodified coefficients;

b) a set consisting of modified coefficients; or

c) a set comprising modified and unmodified coefficients.

A corresponding embedding apparatus and corresponding data removal method and apparatus are also disclosed.

[Figures 3A, B and 4]

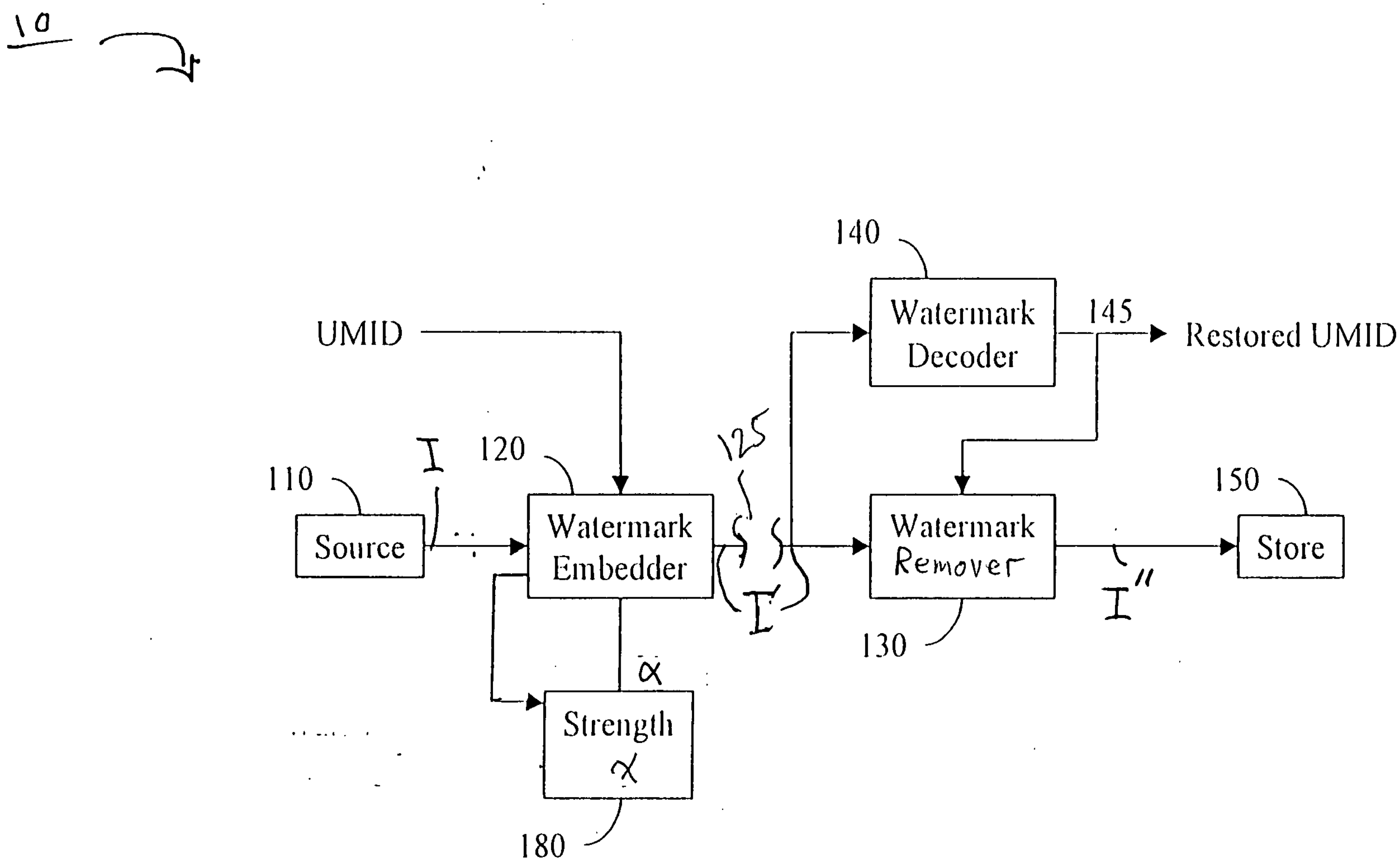
10
UMID
110
Source
I
120
Watermark
Embedder
125
I'
α
Strength
α
180
140
Watermark
Decoder
145
Restored UMID
Watermark
Remover
130
I''
150
Store

Figure 1

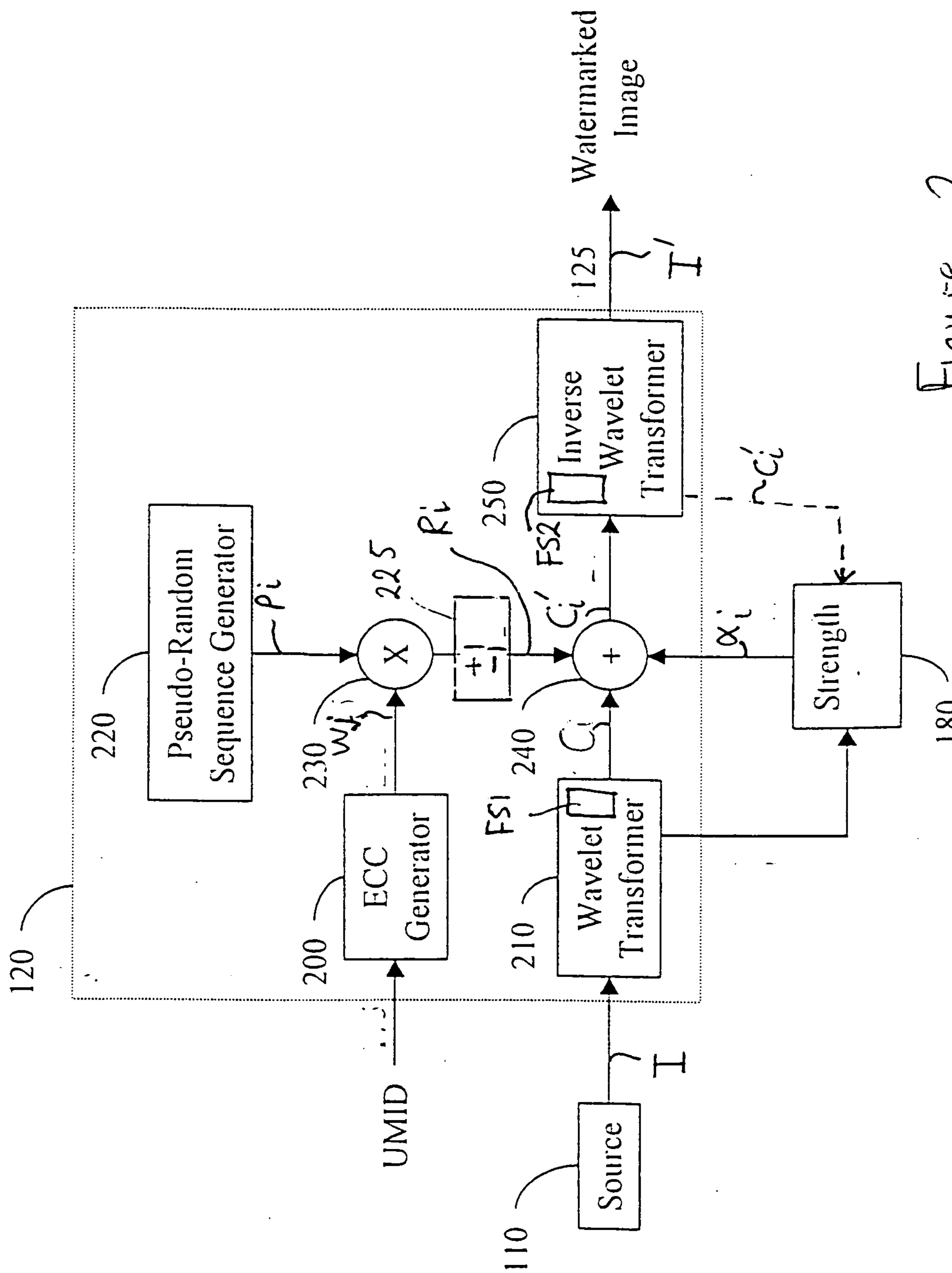

Figure 2

I-00-144

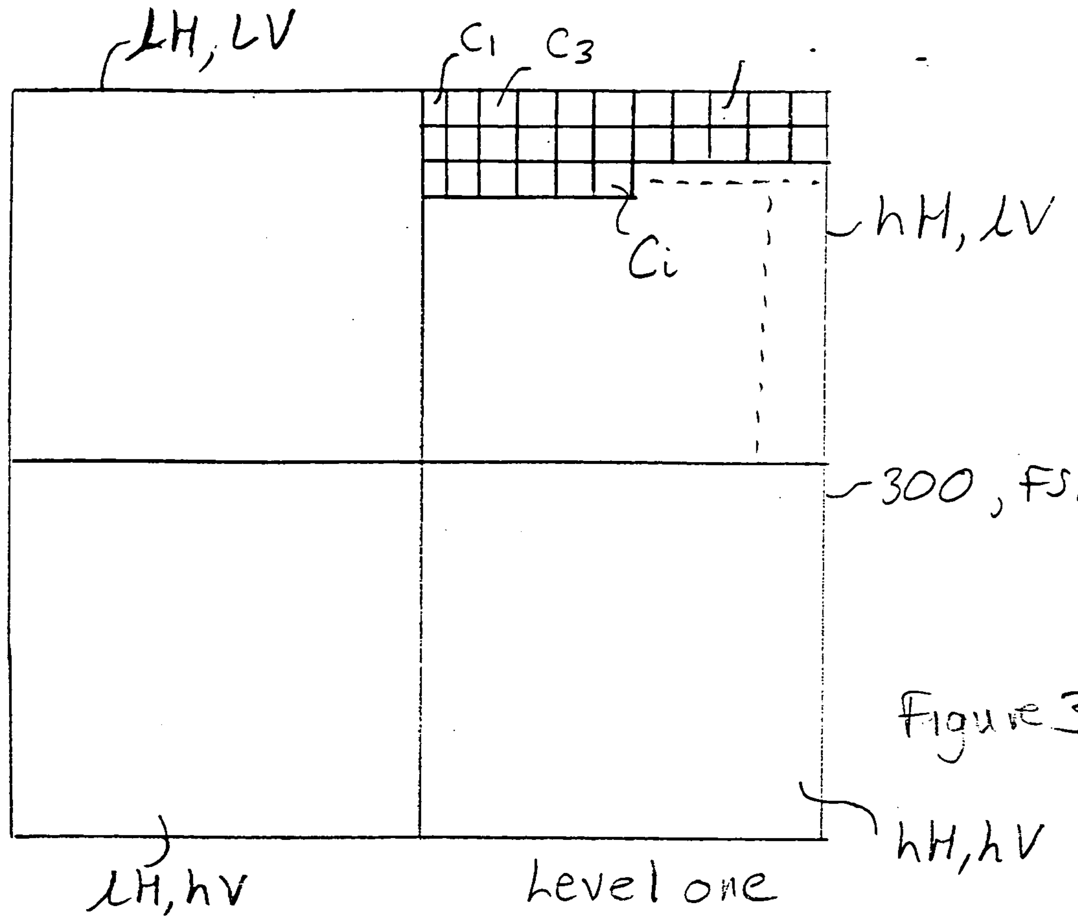

Figure 3A

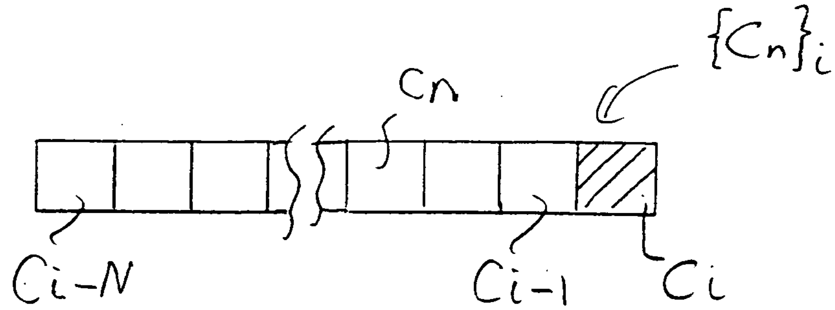

Figure 3B

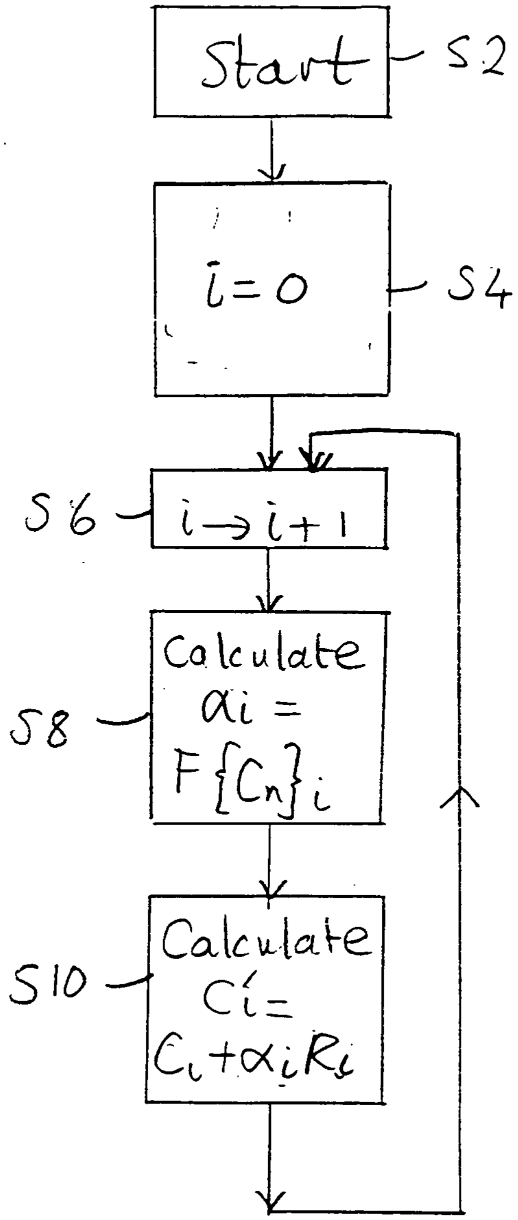
Start
S2
i=0
S4
S6
i→i+1
Calculate
αi =
F{Cn}i
S8
Calculate
Ci′=
Ci+αiRi
S10

Figure 4

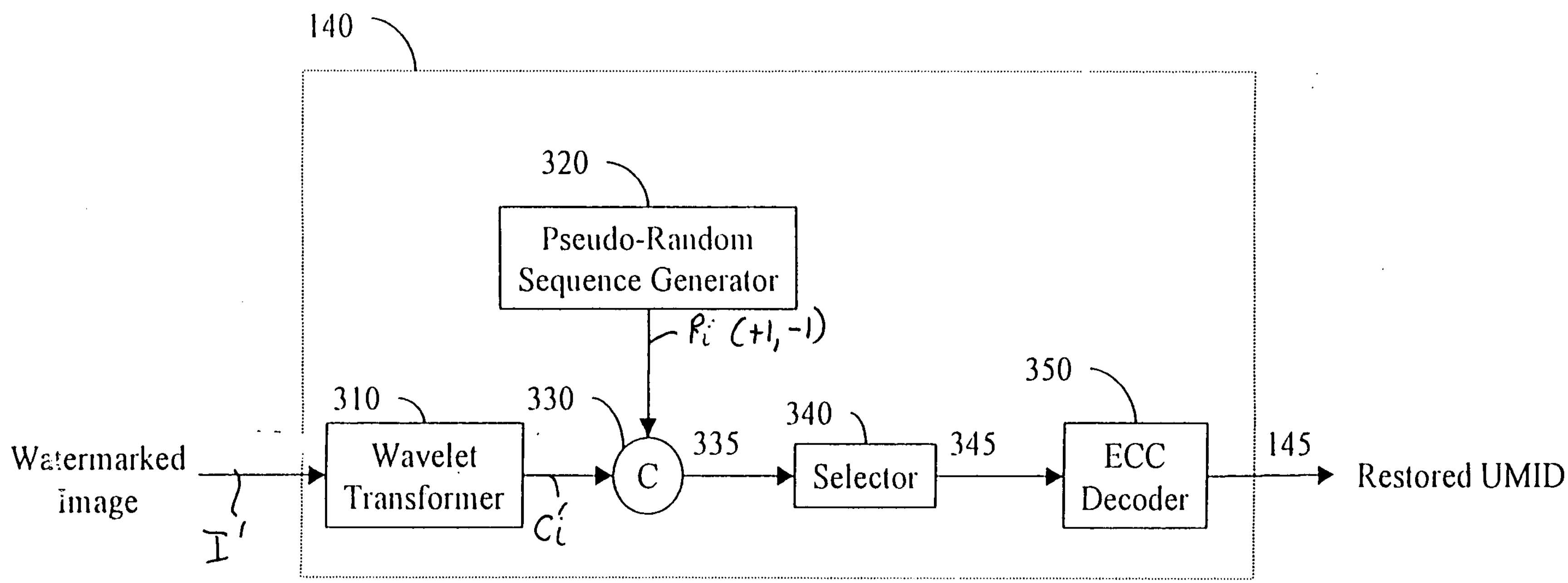
140
320
Pseudo-Random
Sequence Generator
R_i (+1, -1)
310
330
350
340
Watermarked
image
I'
Wavelet
Transformer
C_i'
C
335
Selector
345
ECC
Decoder
145
Restored UMID

Figure 5

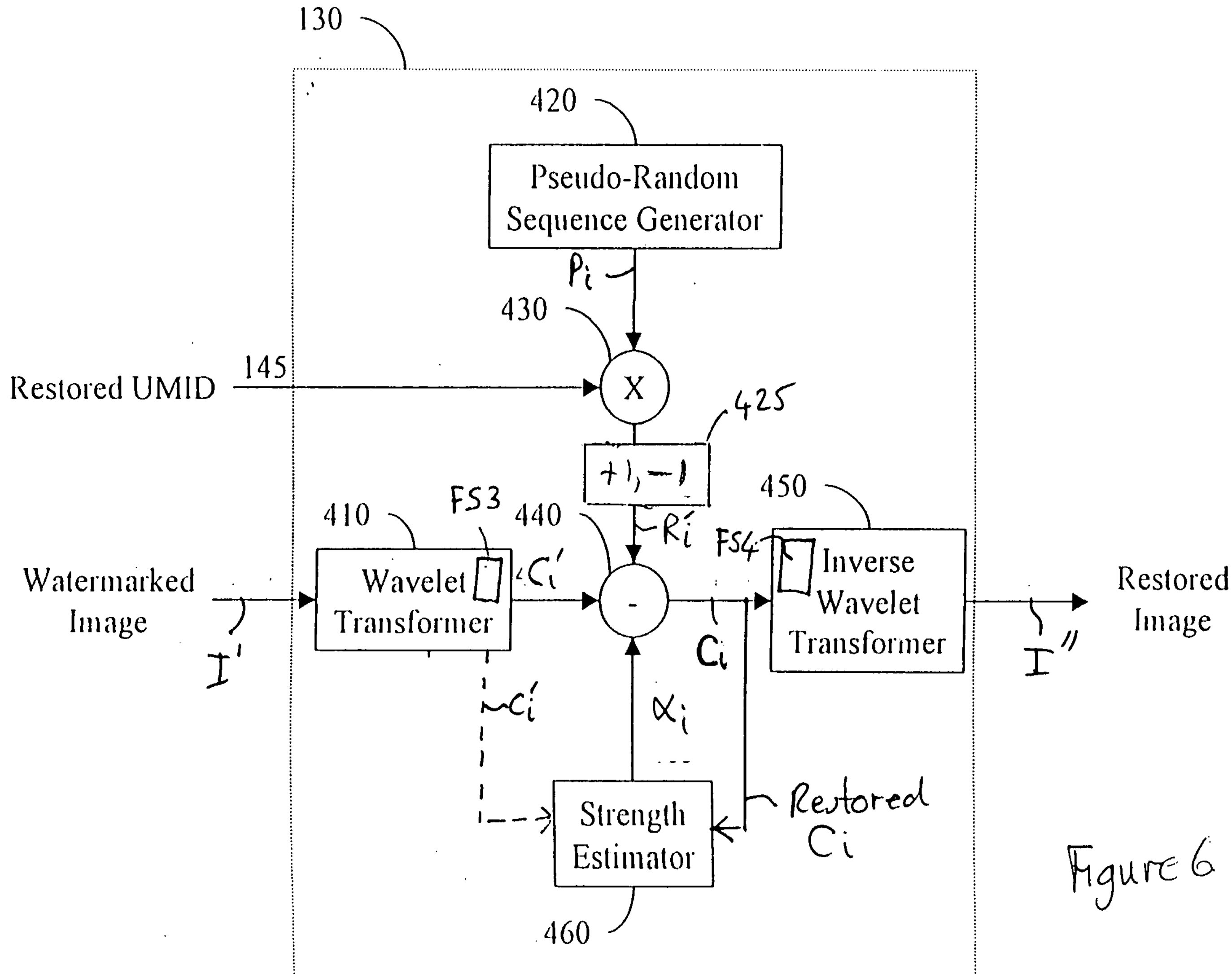

Figure 6

I-00-144

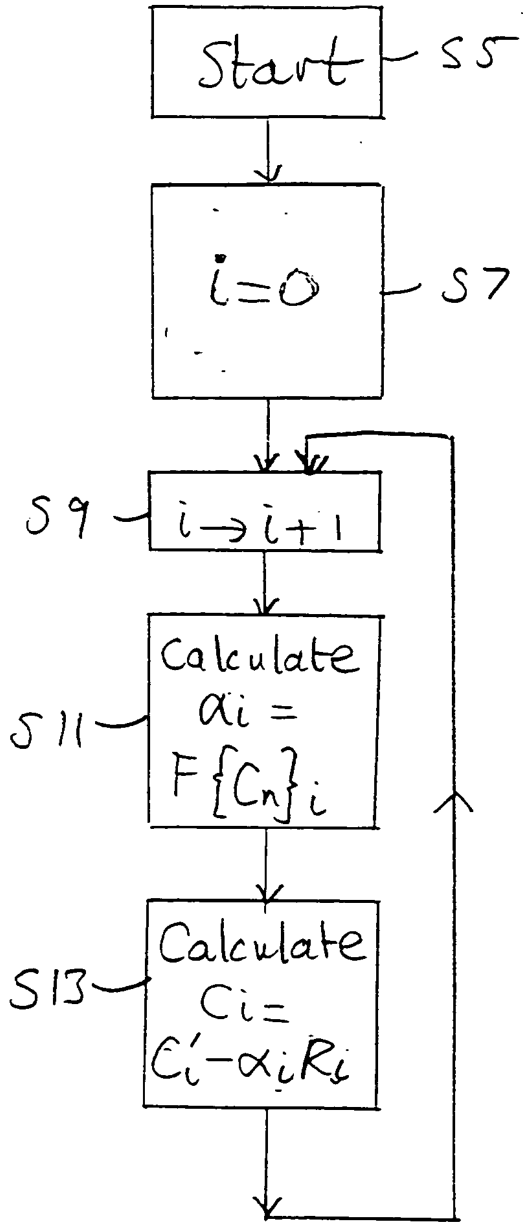
Start
S5
i=0
S7
S9
i→i+1
Calculate
αi =
F{Cn}i
S11
Calculate
Ci=
C'i−αiRi
S13

Figure 7

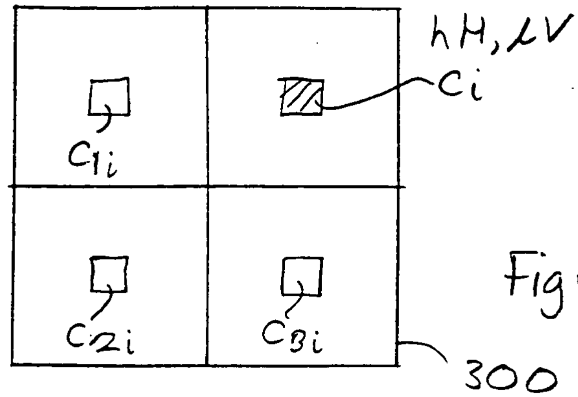

Figure 8

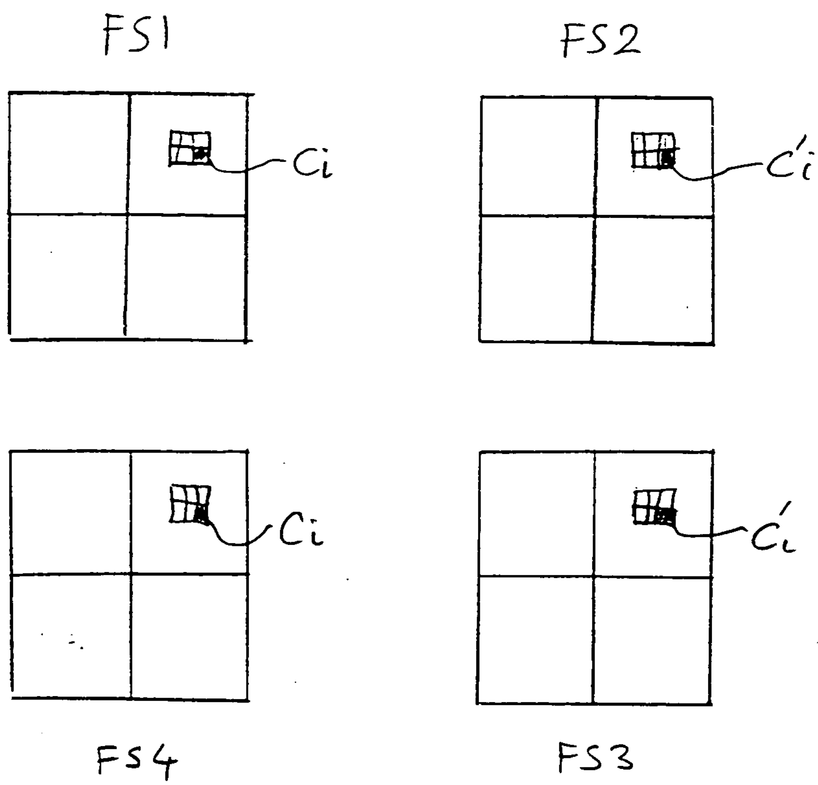

Figure 9

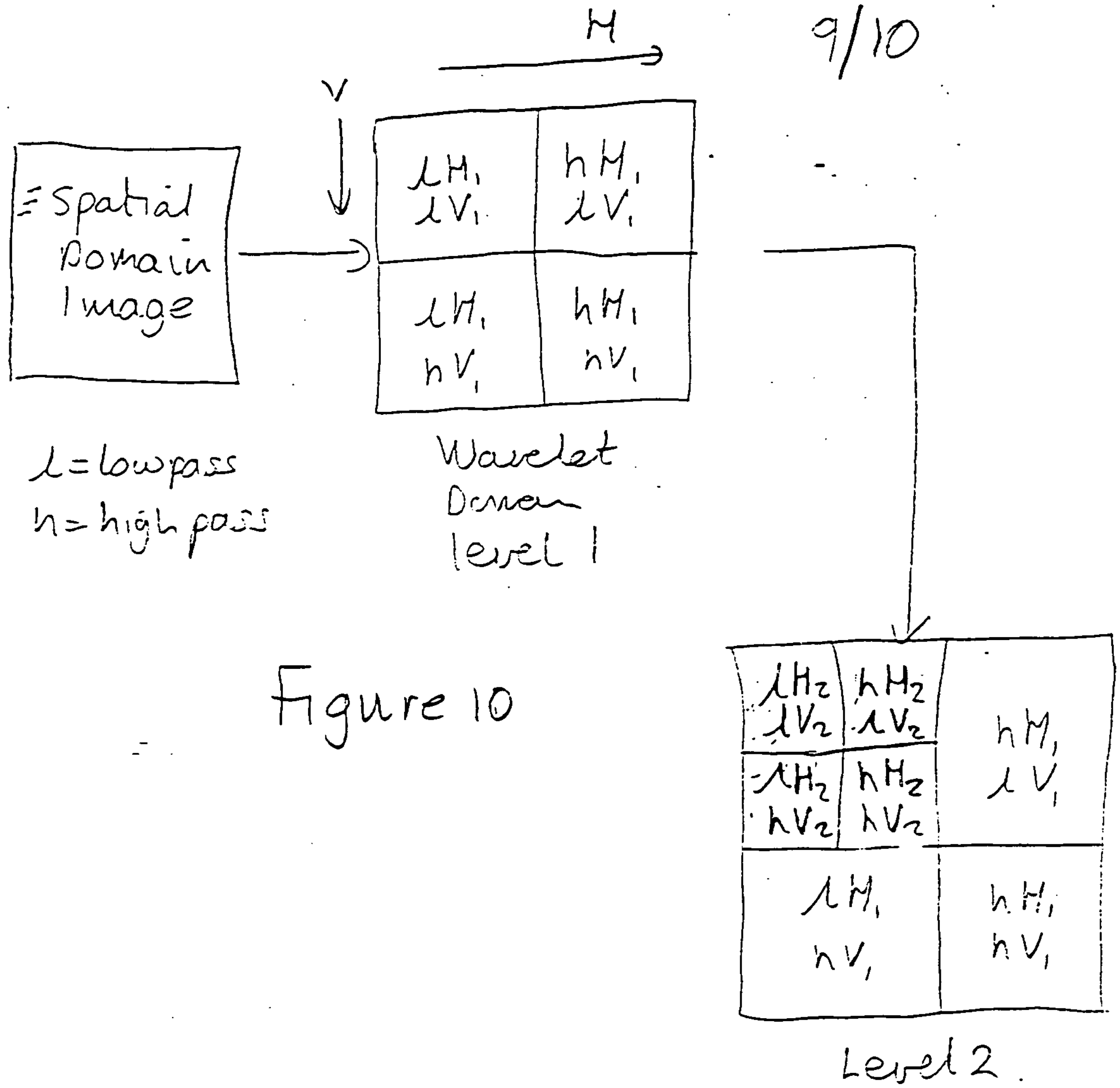

Figure 10

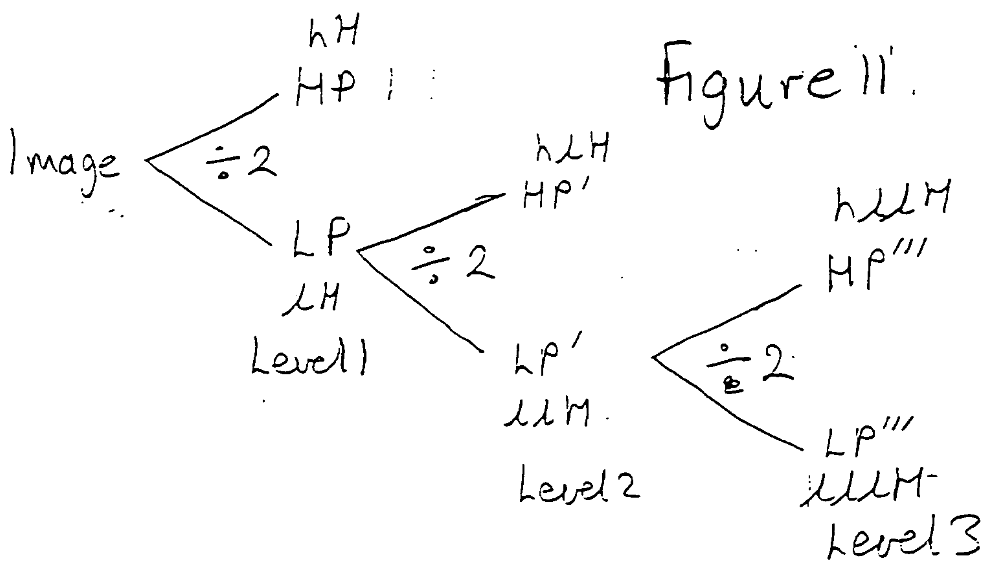

figure 11

Schematic of Wavelet Transform.

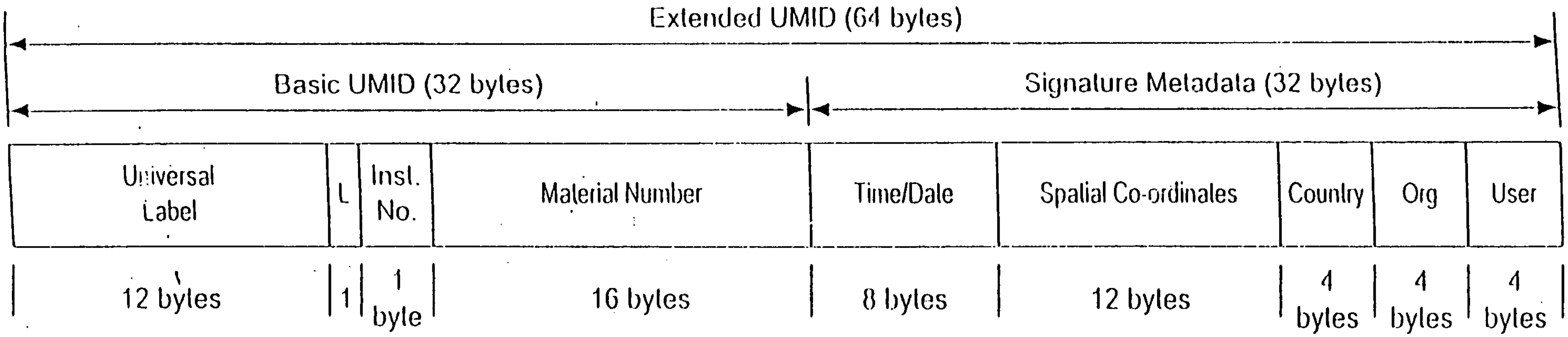

Fig. 12 *Basic and Extended UMID Structures.*

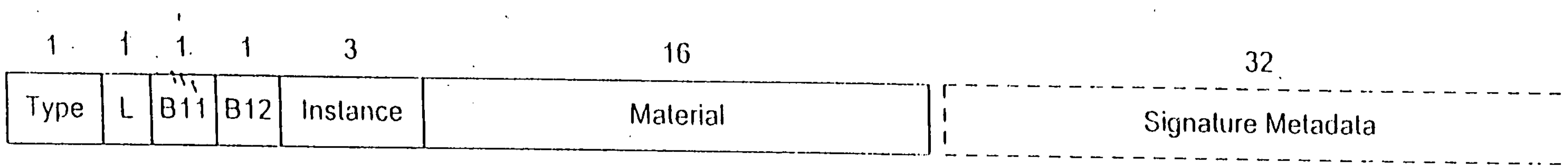

Fig. 13

I-00-144